NEWS

PROTOTYPE SYSTEM: Nikon's beta EUV system, soon to be operational, will be suitable for experimentation but will not be able to make advanced chips.

NIKON CORP.

Plans for Next-Gen Chips Imperiled

Dim lights casting a shadow on extreme-ultraviolet lithography's debut date

Everyone in the chip industry knows that the giddy, exponential curve they've been riding for decades can't go on forever. Some day a "showstopper" will finally appear, signaling an end to the amazing pace at which microprocessors, memory, and other chips have become denser and faster without getting more expensive. Nobody ever expects that dreaded day to be right around the corner. But now, sobering revelations about a futuristic, multibillion-dollar chip-making initiative have thrown a shiver through the industry, raising concerns that the showstopper may be closer than anyone had thought.

As recently as March, researchers were still confident that a technique called extreme ultraviolet (EUV) photolithography would be ready in 2011 to start churning out cutting-edge logic chips. But at an advanced lithography symposium held that month by the photonics society SPIE, experts from IBM and its development partners AMD, Micron Technology, and Qimonda said they do not expect EUV to be ready for its intended debut. Others in the industry, though less blunt, say progress made in the coming year will make or break the deadline.

Historically, each generation of photolithography technology has remained useful for about six or seven years, spanning three size reductions, or nodes, in chip processing. Today's technology uses light with a wavelength of 193 nanometers to produce chips with key parts, or features, that measure just 65 nm. If the seven-year rule holds true, 193-nm lithography will need a replacement by 2012 or 2013.

Before anyone panics, it's important to note that the industry has been consistently wrong about when any particular production technology will hit its limits. But with six years to go, it's clearly crunch time for this technology. "The next year or so is going to be crucial," says Michael C. Mayberry, vice president of Intel's technology and manufacturing group.

Until recent years, semiconductor road maps anticipated challenges developing masks and photoresists capable of handling EUV, but not problems generating EUV light as such [see sidebar, "EUV: Expectations vs. Realities"]. Only in 2005 did the road map spell out the hurdles that would have to be surmounted for EUV lithography to work. Since then, contrary to expectations, obtaining an adequate light source has turned out to be the biggest stumbling block.

A chip's vast profusion of transistors is created by a process of depositing successive layers of metals, insulators, and other materials on a wafer of semiconductor, and then etching away the part of each layer not wanted. The process of defining what goes and what stays is known as photolithography. First the wafer is covered with a chemical called a photoresist. The circuit pattern to be projected on the wafer is drawn on a transparent photomask. The photolithography system shines UV light through the photomask, projecting a shadow of the circuit pattern on the wafer. The photoresist reacts to the light. The parts of the photoresist that react harden and protect the areas directly beneath, allowing everything else to be etched away.

The shorter the wavelength of the light used in the projection, the smaller you can make the transistors and wiring on a chip. EUV sources aim to operate at 13.5 nm—technically, past the ultraviolet part of the spectrum and into the low-energy end of the X-ray band. Transistor features on today's best chips are as small as 65 nm—less than 1 percent the width of the cotton fiber in your shirt. By the time EUV was supposed to come online, they were expected to be around 22 nm.

The EUV wavelength was chosen many years ago, not because there was a good source of 13.5-nm light at hand but because there were good reflectors and filters available. Chip makers expected that, over the years, all the other pieces of the technology would fall into place as they had for other new photolithography systems. But some of those pieces still don't fit. "The biggest challenge is the source," says Michael Lercel, lithography director at Sematech—an independent, nonprofit consortium with a charter to help develop new chip-manufacturing technologies. And the source is intrinsically tied to another problem: a light source has to be paired with new photoresists sensitive to it. But the development process for photoresists, too, has been more painful than predicted.

A commercial EUV lithography system will almost certainly need a source that can operate steadily and reliably at 150 to 200 watts. But in practice, developers of sources for photolithography systems—such as Cymer, Gigaphoton, Philips Extreme, Starfire Industries, and Xtreme Technologies—are still struggling to achieve 10 W on a consistent basis. At a Sematech workshop in late May, Gigaphoton reported an EUV source capable of a record 130 W, but only in short bursts, which suggests but does not prove that it could be made to provide 40 W of usable light. That's good for testing prototype systems, but it's still far too dim and intermittent for commercial use.

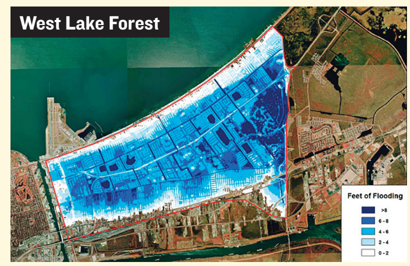
There are two ways to make sources specifically for lithography systems: a discharge-produced plasma (DPP) or a laser-produced plasma (LPP). "A year ago, DPP was in the lead," Intel's Mayberry says. "Today, it's a lot more of a horse race."

Traditional DPP sources use electrodes to conduct enormous pulses of current into tin vapor or xenon gas, turning it into a plasma that radiates EUV, among other wavelengths. But the proximity of the electrodes to the hot plasma and the tremendous current rushing through them cause the electrodes to overheat, melt, and evaporate. This erosion of the electrodes makes DPP systems unreliable and subject to frequent maintenance. Vapor from the electrodes also can gum up the expensive precision optics needed to collect and direct EUV light.

Although it provides less than 10 W of usable EUV light, the DPP source from one company, Energetiq, at least gets around the electrode problem. It does so using a method that CEO Paul Blackborow calls electrodeless Z-pinch. A large current pulse in a loop of wire outside the discharge chamber creates a magnetic field that induces loops of current within xenon gas inside the chamber, heating it to a glowing plasma. The geometry of the source is such that the external magnetic field "pinches"

NEWS BRIEFS

GALILEO'S TRIALS European transport ministers, meeting in early June, failed to breathe new life into the foundering public-private consortium set up to design, build, and operate Galileo, a global-navigation system meant to rival the U.S. GPS and Russian Glonass systems. Construction of Galileo is far behind schedule, and members of the multinational consortium of aerospace companies participating in it were unable to reach an agreement.



Pre-Katrina [above], you had a 1 in 100 risk of flooding to the indicated levels; today [below] your risk of flooding to indicated depths is 1 in 50.

U.S. ARMY CORPS OF ENGINEERS

VIRTUAL NEW ORLEANS The U.S. Army Corps of Engineers has issued a report showing interactively how much each neighborhood of New Orleans is at risk from flooding in 50-year and 100-year storm scenarios. Either by means of Google Earth or PDF overlays, maps show how vulnerable neighborhoods are now [see above], even with the enhanced storm protection system put in place since Hurricane Katrina [see "Protecting the Big Easy From the Next Big One," March]. The corps found that the heart of the hard-hit lower Ninth Ward can still expect to be under 1.2 to 1.8 meters of water once every 50 years and under 1.8 meters or more once in a hundred years. Its report, available at http://nolarisk.usace.army.mil, is a preliminary study of how to protect the city against all but a 100-year storm.

the plasma loops, causing the xenon to emit EUV light while simultaneously keeping it clear of the chamber walls where it can damage the optics. "The plasma is decoupled from the walls it's in," Blackborow says. "It's clean, simple, long-lived." The source is suitable for use in developing the infrastructure for EUV technology, such as testing new photoresists and optics.

In LPP, the alternative to DPP, tin droplets are jetted through the source chamber tens of thousands of times per second. As they fall through the chamber they are hit by pulses from kilowatt-class lasers. The laser pulses turn the tin into an EUV-emitting plasma.

LPP developers, such as Cymer, Gigaphoton, and Xtreme, try to hit all the tin drops in just the right way, and with just the right amount of energy, according to Vivek Bakshi, a senior member of the technical staff in Sematech's lithography division. Too much or too little energy, and the tin plasma does not reach the particular energy state that generates the most 13.5-nm light, Bakshi says. Likewise, hit the droplet with a laser beam that's too broad, compared with the size of the droplet, and the tin will absorb too much energy, because it is still in the beam path even after it expands into a vapor. A beam that's too narrow, or one that's off center, will blast off droplets of debris that muck up the source's optics.

"No one has demonstrated the ability to hit [the tin] consistently," Blackborow says. So in practice the emitted EUV flickers too much to work in an industrial-scale setup.

The brighter the light, in general, the less time it takes to expose the photoresist and the faster the whole chip-making process runs. Chips today are produced by the hundreds on a 300-millimeter-diameter wafer. Commercial systems will have to process 100 of those wafers per hour. So whether the chip industry can settle for a mere 100 W or must wait for still brighter sources depends on how sensitive photoresists can be made. If the resist is so sensitive to 13.5-nm light that it needs to collect only a few thousandths of a joule of energy to set, a low-power source will provide those millijoules quickly enough for commercial throughput rates.

But so far, there has been little to cheer the chemists struggling with photoresist development. A few years ago, they thought it might be possible to develop a high-quality resist that would require only 1 or 2 millijoules of EUV energy per square centimeter to set. But they've had to scale back their expectations. Now the goal is a 5-mJ resist, which could be paired with a 115-W source to get an acceptable commercial throughput. A 15-mJ resist would probably need a 150-W source, and a 20-mJ resist would likely have to be paired with a source at 200 W or more. Sematech's Lercel says the very-high-resolution resists that some laboratories are using today are usually rated somewhere between 30 mJ and 50 mJ.

Christopher Sparkes, senior director of technology at Nikon Precision, a Japanese lithography systems manufacturer, says that a 15-mJ resist—which would require a 150-W source—might be the best that can be hoped for. But Intel's Mayberry says that's overly pessimistic.

There are, of course, other hurdles to getting EUV ready besides the source and resists, including new photomasks to carry the circuitry pattern and multilayer reflectors to steer the EUV beam. But these technologies have reached the point that major photolithography companies ASML, Canon, and Nikon are rolling out demonstration machines with weak light sources.

ASML has a test system it's calling an alpha tool—suitable for experimentation only. It has shipped two. Canon is also preparing an alpha machine.

Nikon already has at least one alpha model in operation in Japan, and plans to have a beta, dubbed the EUV1, ready by the end of 2007 [see photo, "Prototype System"]. The EUV1 also will be suitable only for experimentation, but Nikon is justifying the beta tag with the claim that the system can be upgraded for use in production with the addition of a powerful enough source, when available.

Provided that it does, in fact, become available.

Energetiq's Blackborow says the fact that ASML has shipped a system, unsuitable though it is for commercial use, is being taken as a very good sign. G. Dan Hutcheson, CEO of market analysis firm VLSI Research, agrees. But he points out that, judging from the path of earlier lithography innovations, it would take five or six years to thoroughly test a new production process and all the equipment in a new production line—and that's only if EUV were production-ready today.

Wisely, chip makers and their equipment suppliers are exploring alternatives, particularly those processes that will let them extend today's lithographic technology. One option is to replace the minuscule air gap between the lenses and the wafer with water or some other fluid, to alter the way the light bends and produce finer features, and then expose the wafer twice or more using different masks. The double patterning produces finer features, but it requires twice the number of photomasks, has slower exposure times, and frequently requires an extra etch step. That means higher costs and lower throughput, according to Sparkes. Nonetheless, ASML, Intel, Nikon, and others are developing the technology, in the increasingly likely case it is needed.

—BRIAN SANTO

EUV: Expectations vs. Realities

The 2001 and 2003 semiconductor road maps contain long tables detailing progress that will have to be made with masks and photoresists when extreme-ultraviolet radiation comes into play as the main lithography tool, but no discussion of EUV as such in their sections discussing "difficult challenges" in lithography.

Only in the 2005 road map does there appear a paragraph listing the main challenges of EUV. They include "developing mask blank fabrication processes with low defect density; developing EUV sources with high output power and sufficient lifetime for surrounding collector optics; controlling contamination of all mirrors in the illuminator and projection optics; fabrication of optics with figure and finish compatible with high-quality imaging at 13.5-nanometer wavelength; resist with sufficiently low line width roughness and low exposure dose; and protection of masks from defects without pellicles."

How is the industry doing? In brief—

- Development of optics: well enough.
- Photoresists: not quite as well as hoped in terms of matching resists to available light power.
- EUV light sources: far behind schedule.